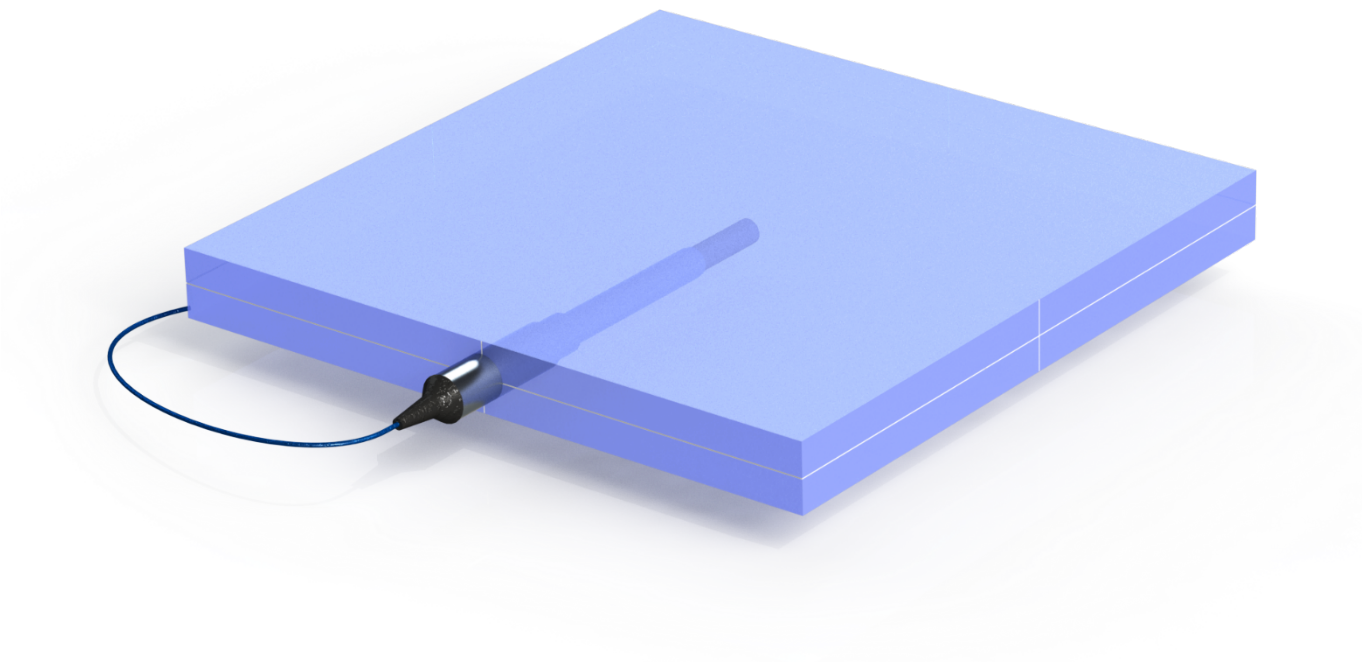
Solid Water® HE:

On the Dosimetric Accuracy of a Next-Generation Water Mimicking Solution



Your Most Valuable QA and Dosimetry Tools

Introduction

Dosimetry protocols have always specified water as the standard reference material for quality assurance of radiotherapy systems. However, in practice it is not always feasible to setup water phantoms for routine QA tests due to time limitations.

Solid phantoms have been accepted by the medical physics community as a convenient surrogate for water because they offer quick setup and teardown. In order to serve as an equivalent substitute, a solid phantom must have similar radiation scattering and absorption characteristics as water, and for dosimetry it must not store electric charge [1, 2].

History

Solid Water® was first coined in the late 1970's when Dr. Chris Constantinou joined RMI to begin production of a formulation – Model 451 for photon dosimetry – based on his collaborative research with Dr. David White [3]. Improvements were made to include electron dosimetry, leading to Solid Water Model 457 in the 1980's, which quickly became a gold standard for routine quality assurance of both photons and electrons.

Recent advancements have led to further an improved formulation known as Solid Water High Equivalency (HE), Model 557.

HE Advantages

Solid Water HE demonstrates water equivalency for both electron and photon dosimetry in the therapeutic energy range, as well as improvements in uniformity, durability, and relative electron density. These advantages make Solid Water HE among the most accurate water equivalent dosimetry phantoms available. The improved uniformity also allows substitution into diagnostic phantom applications that historically use pure compounds such as Acrylic (PMMA).

Uniformity

The formulation of Solid Water HE includes glass spheres with a diameter of <100 microns to precisely control density while yielding premium uniformity. Uniformity is important to emulate the scatter and absorption characteristics of a uniform material, such as water. Uniformity is also critical to eliminate setup variability from the phantom itself, allowing users to make repeatable constancy measurements.

Every slab of Solid Water HE is imaged to verify uniformity. Figure 1 demonstrates a CT image of a slab with chamber cavity. Sophisticated inspection algorithms are used to show the product is free from artifacts, graininess, and impurities.

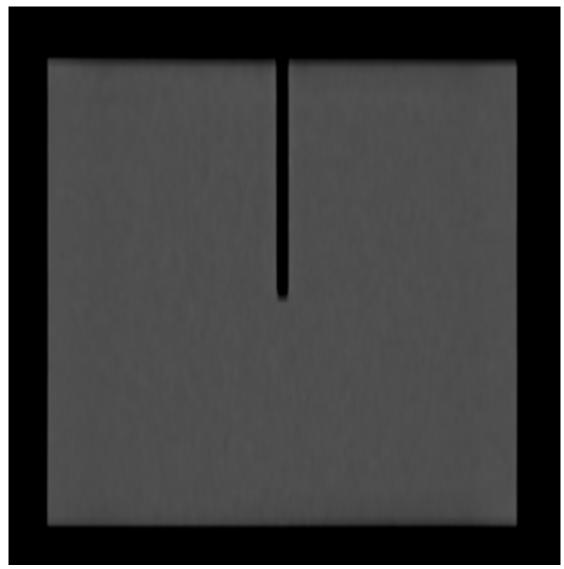


Figure 1 – 120 kVp CT image of Solid Water® HE chambered slab (SN 21341-1) demonstrating the material's superior uniformity that is free of all artifacts.

Durability

Solid Water slabs are the workhorse for routine QA measurements, constantly being stacked, slid, and stored. Because wear and tear are an important consideration when purchasing QA tools, Solid Water HE has been blended with glass spheres to provide improved hardness, resisting scratches and breaks thru the strength of a chemically cross-linked epoxy polymer.

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e^- Density

The formulation of Solid Water® HE was carefully balanced to match to the electron density and attenuation coefficient of water while still maintaining characteristics needed for accurate dosimetry. The end result is a material that matches the electron density of water to within 0.5%.

A number of publications have indicated that matching the electron density is an effective approach to emulating the radiological characteristics of water [2, 4]. In order to match the electron density to water, the physical density of Solid Water HE must be scaled up to 1.032 g/cm^3, such that within a unit thickness, the beam transmission for both are equal [2].

Water Equivalency

The most important feature of Solid Water HE is the ability to back its claim, "High Equivalency." One method to demonstrate the degree of water equivalency of Solid Water HE is through percent depth dose (PDD) measurements and Monte Carlo (MC) calculations.

Measurements were made on a Varian Clinac 21EX with a range of electron and photon beams, in a water tank and subsequently in Solid Water HE slabs using an ionization chamber. MC calculations were also made with the DOSXYZ algorithm for the same setup conditions.

Methods

Table 1 lists settings and equipment utilized for the data acquisition. A reference chamber was also used for normalization of field data. Depth dose profiles in water were collected on the central axis at a resolution of 0.5 mm for all beam qualities of interest.

Slabs of Solid Water HE were setup at reference conditions with an A1SL chamber placed into the cavity of a 2-cm thick, 30 x 30 cm^2 slab. Subsequent depths were reached by stacking additional slabs, while maintaining the SSD. 200 MU was delivered and recorded at each depth for each beam quality.

Table 1 – Specifications for photon/electron measurements

System		
	Machine:	Varian Clinac 21EX
Reference Conditions		
	Field Size:	15 x 15 cm^2
	SSD:	100 cm
	Nominal Energies:	6, 18 MV photons
		6, 12, 20 MeV electrons
Equipment		
	Detector:	Exradin A1SL
	Electrometer:	Sun Nuclear PC Electrometer™
	Tank:	Sun Nuclear 1D SCANNER™
	Slabs:	Solid Water® HE (30 x 30 cm^2)

MC simulations were preprogrammed to match reference conditions of the linac. The incident source spectra, collected from Mohan et al. [5] for 6 MV and IAEA phase-space data for 18 MV, was modified to match depth dose profiles in water. Mass density and elemental composition were entered for water and Solid Water HE. Source geometry was layered and voxelized to provide adequate resolution for particle scoring.

Results

Table 2 shows key parameters comparing measured water data versus Solid Water HE measured and MC calculated values. Measurements in water are the standard against which the Solid Water HE measurements and MC calculations were compared.

▸ PHOTONS

Photon depth dose in water and Solid Water HE are normalized to match at 10 cm for 6 MV & 18 MV photons, as plotted in Figure 2. The average absolute difference (relative to D_{max}) between Solid Water HE measurements versus water are 0.43% and 0.40% for 6 MV and 18 MV, respectively, for all depths at $d \geq d_{max}$. For 6 MV MC calculated, the absolute average difference versus water measurements was 0.39%. In addition, the key values of d_{max}, PDD_5, and $TPR_{20,10}$ are reported in Table 2.

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Photon beam quality is specified by the tissue-phantom ratio, $TPR_{20,10}$, per IAEA Technical Report Series (TRS) No. 398 [6]. Although exact IAEA reference conditions were not used here, calculated $TPR_{20,10}$ values in Solid Water® HE versus water showed agreement within 0.32% for both 6 & 18 MV. Note $TPR_{20,10}$ values were calculated from $PDD_{20,10}$ values per the empirical conversion formula referenced by TRS-398 [6].

ELECTRONS

The results of measurements in water and Solid Water HE for 6, 12, 20 MeV electrons are plotted in Figure 3, while key values R_{100}, R_{90}, R_{50}, and R_P are tabulated in Table 2. Electron PDD's are normalized to maximum dose (D_{max}) for each dataset.

The average absolute difference between Solid Water HE versus water measurements was 0.5%, 0.2%, and 0.3% for 6, 12, and 20 MeV, respectively. For all energies the R_{100} value was within 0.03 cm of water and R_{50} within 0.06 cm.

For 6 MeV MC calculated, the average absolute difference versus water measurements was 0.3%.

Table 2 – Results of comparison between Solid Water HE® measurements and MC calculations to measurements in water. All depth dose values reported are for datasets normalized by their respective D_{max}. Note MC calculations are preliminary and subject to change without notice. "N/A" indicates MC calculations were not yet available.

Energy	*Data*	*Water Meas. (Reference)*	*HE SW Meas.*	*HE SW MC Calculated*	*Meas. Abs. Difference*	*Calc. Abs. Difference*
6 MV	d_{max} (cm)	1.33	1.31	1.37	0.02	0.04
	PDD_5 (% D_{max})	86.78%	87.18%	86.33%	0.40%	0.45%
	$TPR_{20, 10}$	0.6893	0.6915	0.6881	0.0022	0.0012
18 MV	d_{max} (cm)	2.75	2.79	N/A	0.04	N/A
	PDD_5 (% D_{max})	94.88%	95.27%	N/A	0.39%	N/A
	$TPR_{20, 10}$	0.7964	0.7966	N/A	0.0003	N/A
6 MeV	R_{100} (cm)	1.31	1.30	1.33	0.01	0.02
	R_{90} (cm)	1.75	1.70	1.78	0.05	0.03
	R_{50} (cm)	2.30	2.30	2.31	0.00	0.01
	R_P (cm)	2.77	2.82	2.87	0.04	0.09
12 MeV	R_{100} (cm)	2.85	2.85	N/A	0.00	N/A
	R_{90} (cm)	3.84	3.86	N/A	0.02	N/A
	R_{50} (cm)	4.91	4.93	N/A	0.02	N/A
	R_P (cm)	5.96	5.94	N/A	0.02	N/A
20 MeV	R_{100} (cm)	2.45	2.44	N/A	0.01	N/A
	R_{90} (cm)	5.89	5.90	N/A	0.01	N/A
	R_{50} (cm)	8.25	8.31	N/A	0.06	N/A
	R_P (cm)	10.02	10.16	N/A	0.14	N/A

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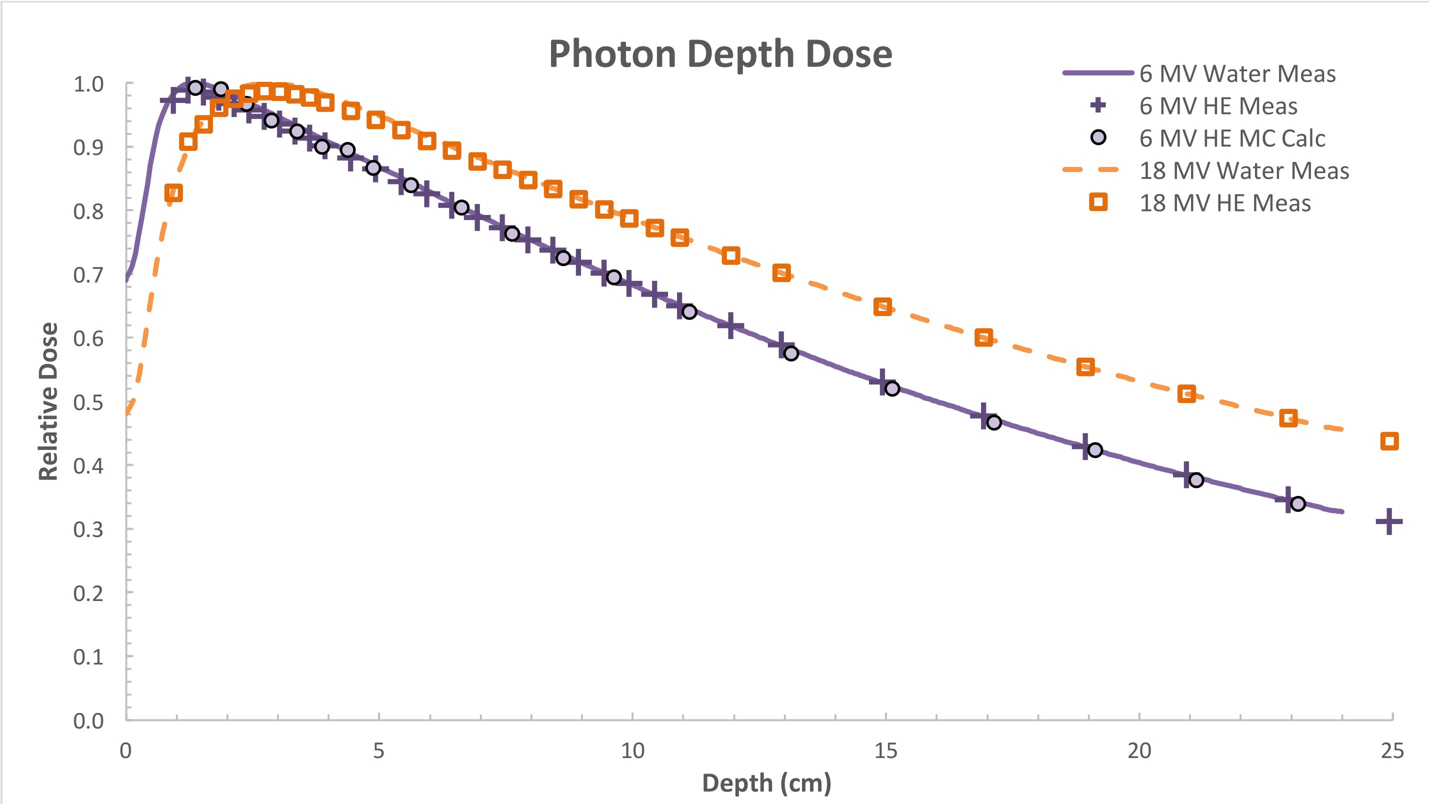

Figure 2 – Photon Depth Dose for 6 & 18 MV in Water and Solid Water® HE. MC and measured HE data are scaled to match water at 10 cm depth.

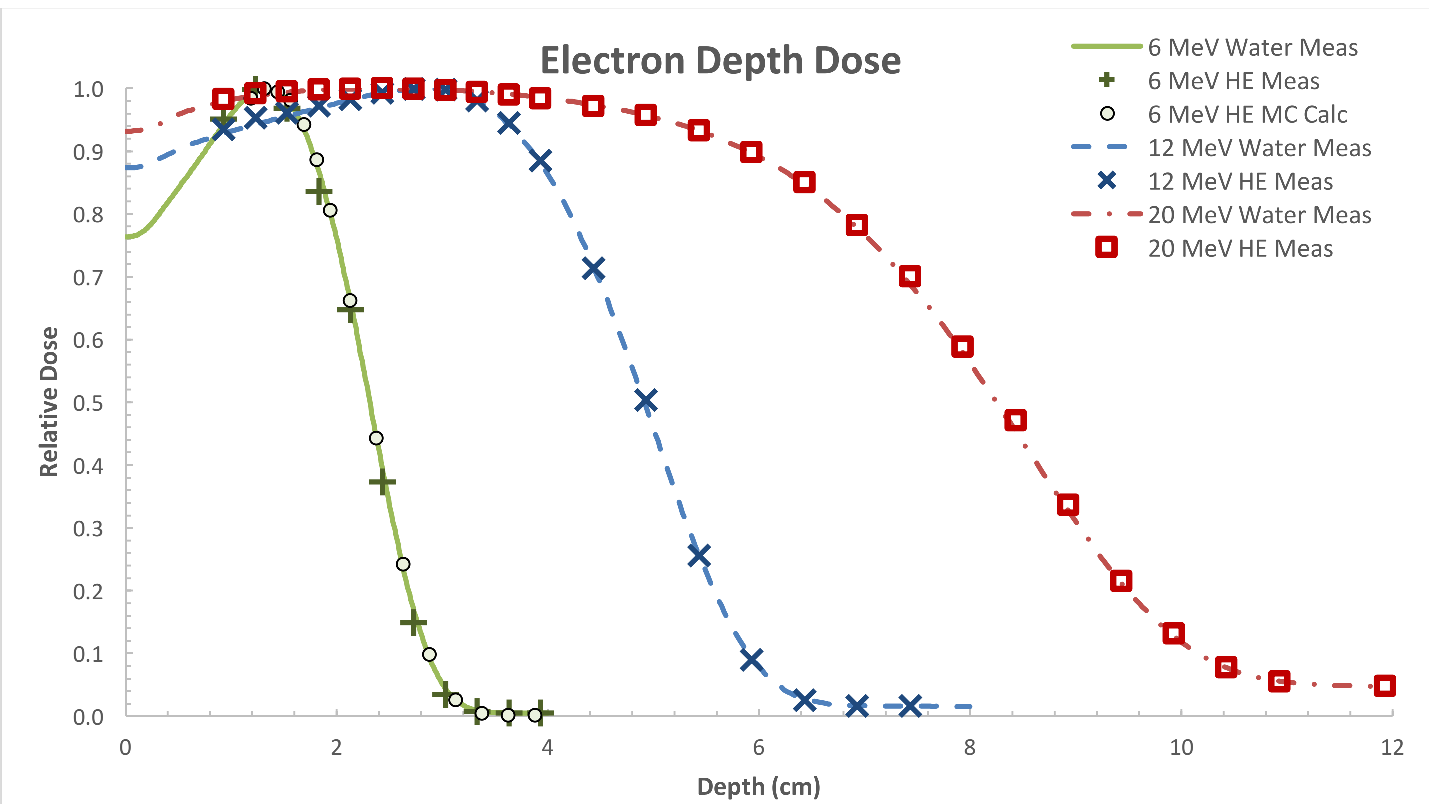

Figure 3 – Electron Depth Dose for 6, 12, & 20 MeV in Water and Solid Water HE.

Conclusions

Solid Water® HE is a premium-grade dosimetry product for QA checks within 0.5% of water. Measurement and MC simulation demonstrated the water equivalency. New formulation methods enhance uniformity properties for diagnostic applications, while adding the benefit of improved durability.

References

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